Technical Memorandum

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Subject: Detailed Assessment of Phosphorus Sources to Minnesota Watersheds – Deicing Agents

Date: December 17, 2003

Project: 23/62-853 DEIC 008

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The purpose of this memorandum is to provide a discussion on deicing agents as sources of phosphorus to Minnesota watersheds. This discussion is based on a review of the available literature, monitoring data and the results of phosphorus loading computations done for each of Minnesota's major watershed basins as part of this study. This memorandum is intended to:

- -- Provide an overview and introduction to deicing agents as a source of phosphorus
- -- Describe the results of the literature search and review of available monitoring data
- -- Discuss the characteristics of each watershed basin as it pertains to deicing agents as a source of phosphorus
- -- Describe the methodology used to complete the phosphorus loading computations and assessments for this study
- -- Discuss the results of the phosphorus loading computations and assessments
- – Discuss the uncertainty of the phosphorus loading computations and assessment
- – Provide recommendations for future refinements to phosphorus loading estimates and methods for reducing error terms
- -- Provide recommendations for lowering phosphorus export from deicing agents

Overview and Introduction to Deicing Agents as Source(s) of Phosphorus

The use of deicing chemicals has increased in the U.S. since the 1940s and 1950s to provide "bare pavement" for safe and efficient winter transportation. As more and more transportation agencies adopted the "bare pavement" policy, the use of salt, salt and sand mixtures, liquid brines and alternative deicers increased with the need to maintain this standard for pavement conditions during inclement weather. Sodium chloride (NaCl) is one of the most commonly used deicing chemicals. Concern about the effects of sodium chloride on the nation's environment and water quality has increased with this chemical's continued usage.

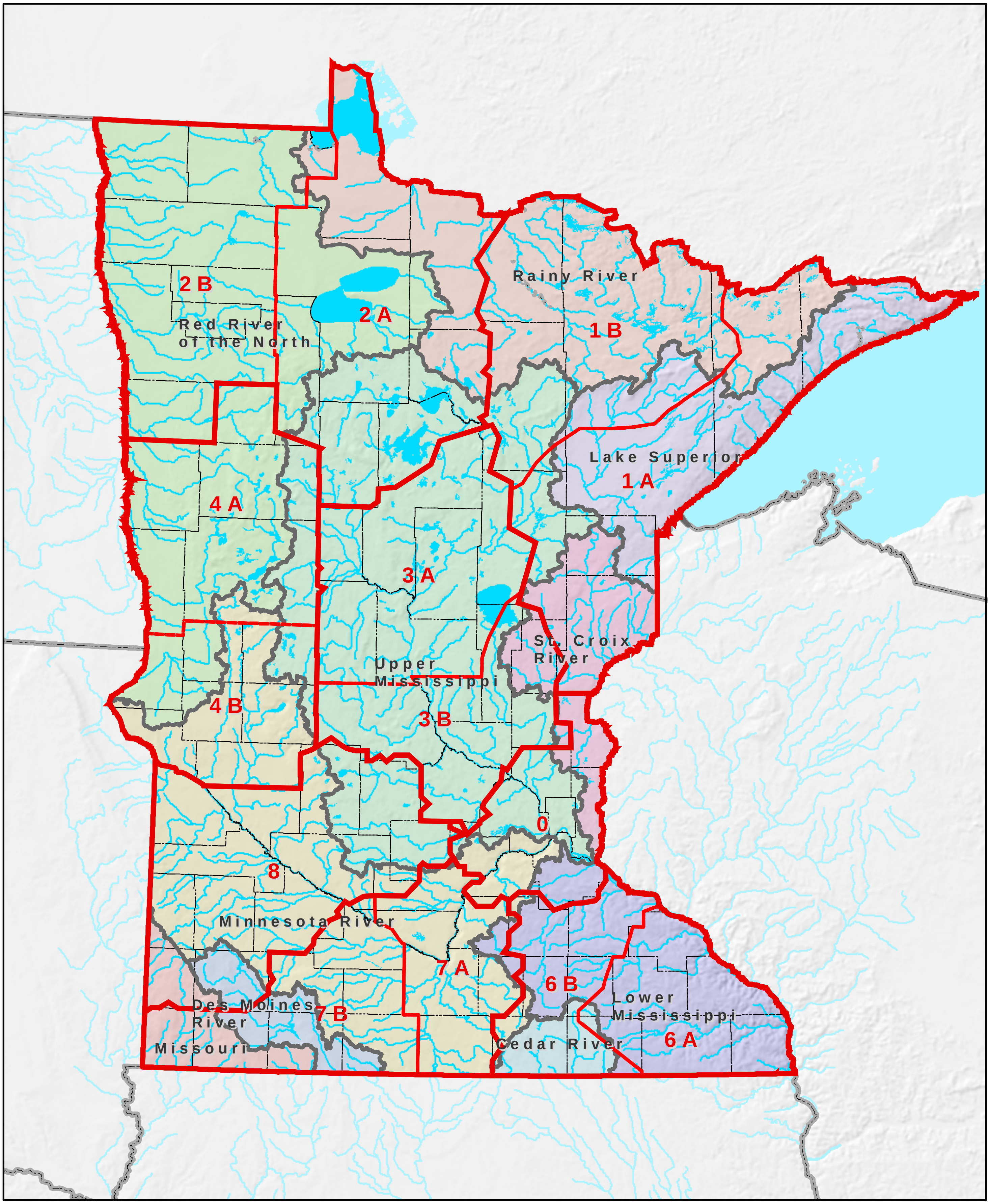
As environmental and associated impacts of salt usage became better documented, the Minnesota Department of Transportation (MnDOT) began implementing procedures to reduce the usage of salt and sand on the state maintained roadway system. In 1996 MnDOT conducted a pilot project – Salt Solutions – to develop tools for reducing their usage of deicing agents, while maintaining safe roadways (SRF Consulting Group, 1998). Following a successful pilot project in winter of 1996-97, the program was adopted state-wide. Other road agencies in Minnesota such as cities, townships and counties use deicing agents to maintain a similar standard for pavement conditions during inclement weather. Many of these agencies have less rigorous record keeping programs than MnDOT.

The search for alternatives to salt for road deicing has been prompted primarily due to the infrastructure corrosion concerns and the impacts of chloride on water quality and vegetation. Recent research in Colorado, New York, and British Columbia have documented water quality concerns related to phosphorus and other chemicals present in deicing agents, as well as the alternative compounds. Due to the recent nature of the work on phosphorus in road salt and alternative deicers, the amount of information present in the scientific literature is somewhat limited, scattered, and quite variable in quality.

Results of Literature Search and Review of Available Monitoring Data

Review of the existing scientific literature with regard to deicing agents as a phosphorus source was concerned with three major areas; 1) usage patterns of deicing agents in Minnesota and other states with regard to road types and road management agency, 2) the phosphorus content of deicing agents – salt, sand, and deicing alternatives, and 3) the impact of weather patterns on usage levels.

The data available for the usage patterns of deicing within the state of Minnesota available from MnDOT is extensive and detailed (MnDOT, 2003; MnDOT Office of Maintenance. 2003; MnDOT Office of Transportation Data & Analysis. 2002). MnDOT has undertaken extensive analyses of usage patterns with regard to road type, service levels and weather patterns. In 1996 MnDOT began a program to reduce the usage of deicers in District 1 and has subsequently expanded the program statewide (SRF Consulting Group, 1998). Figure 1 provides the MnDOT District boundaries in relation to the basin boundaries. The Minnesota Office of Legislative Auditor completed a report that identified some of the best techniques for snow and ice control in Minnesota with the purpose of



Major Basins

Subdistricts

MnDOT Districts

Counties

NORTH

0 12.5 25 50 75 100 Miles

FIGURE 1
Major Basins with MnDOT
Subdistricts

cataloging effective methods of snow and ice control and to encourage the adoption of practices as appropriate throughout the state (Minnesota Legislative Auditor, 1995). While this report attempted to identify practices, it provided little quantitative data on application rates and usage levels. Table 1 presents a summary of the local government salt to sand mix uses from this report.

The states of California, Colorado, Michigan and New Hampshire; as well as the province of British Columbia, Environment Canada and the U.S. Department of Transportation Federal Highway Administration have undertaken studies on the usage of deicing agents in an effort to document and reduce the environmental impacts of their use (Environment Canada and Health Canada, 2001; Fischel, 2001; Goldman, and Hoffman, 1975; Lewis, 1999; Public Sector Consultants, 1993; U.S. Department of Transportation Federal Highway Administration, 1996; Warrington, 1998; University of New Hampshire, 1996;) In nearly all cases, the various studies recommend that service levels be established to define acceptable road conditions and deicing guidelines that define the frequency of winter maintenance and service level needs based upon weather conditions. MnDOT and many other road agencies have developed and implemented sand and salt application guidelines to ensure safe roads and minimize the application of deicers. MnDOT has established targets for snow and ice removal based upon service levels:

Road Class	**Avg. Annual Daily Traffic**	**Target Time to Bare Lane**
Super Commuter	More than 30,000	1-3 hours
Urban Commuter	10,000-30,000	2-5 hours
Rural Commuter	2,000-10,000	4-9 hours
Primary	800-2,000	6-12 hours
Secondary	Under 800	9-36 hours

Attainment of the desired pavement conditions is dictated by several factors, including weather conditions and pavement temperature. Weather conditions, precipitation type and temperature determine the deicing mixture (ratio of sand to salt) or compound to be used, the rate of application (quantity per lane mile) and the frequency of application. The summary data for the state highway system and Twin Cities Metropolitan Area (TCMA) county roads in Tables 2 and 3 illustrates how the implementation of the maintenance guidelines is impacted by weather and the road service level needs across the state and TCMA counties.

Many local road agencies such as the City of Duluth and some out-state counties have adopted application guidelines similar to MnDOT guidelines, but a review of the literature yielded few examples of specific guidelines (Duluth Streams, 2003; SRF Consulting Group, 1998). Review of Minneapolis and St. Paul NPDES stormwater permit annual reports, various MnDOT reports and a database prepared by the Ramsey-Washington Metro Watershed District provided some information related to annual usage rates. In most cases the information in these reports did not provide detailed usage data that could be converted to lane mile usage levels. Lane mile usage levels were calculated or provided for the MnDOT data (City of Minneapolis and Minneapolis Park and Recreation Board, 2003; Weber, 2003; Watson, 2003; Ramsey-Washington Metro Watershed District. 1999; SRF Consulting Group, 1998;). SRF Consulting Group (1998) provided information on usage rates for the TCMA county road agencies for the winter of 1994 – 98. Information provided by Minnesota

Legislative Auditor (1995) indicates that many local units of government use higher ratios of sand to salt than does MnDOT. Some counties, such as Pine, St. Louis and Lake, report the use of sand only for winter road maintenance, while data for the eight TCMA counties indicates that the TCMA counties use a higher salt to sand ratio than what was indicated for other counties across the state (SRF Consulting Group, 1998). In many areas of the state MnDOT, some cities and counties now exclusively use salt without the use of sand for road deicing purposes.

Table 1. Percent of Local Governments Using Various Ratios of Sand to Salt in Mix (from: Minnesota Legislative Auditor, 1995)

Percent of Sand in Mix	Counties (n = 68)	Cities (n = 137)	Townships (n = 6)
99 to 90%	47%	28%	50%
89 to 80%	29%	39%	17%
79 to 70%	15%	10%	0
Less than 70%	3%	9%	16%
No Reply	6%	14%	17%

Table 2. MnDOT Sand & Salt Application Summary Analysis (Winter of 2002-2003)

Summary per District			
District	**Average Sand (Tons)/LM**	**Average Salt (Tons)/LM**	**Salt: Sand Ratio**
1	7.8	6.9	0.5
2	3.5	2.5	0.4
3	3.5	5.8	0.6
4	3.4	3.5	0.5
METRO	0.4	11.4	1.0
6	4.5	8.0	0.6
7	2.2	3.3	0.6
8	3.6	2.6	0.4
STATEWIDE	3.5	5.9	0.6
Summary per Service Level			
Service Level	**Average Sand (Tons)/LM**	**Average Salt (Tons)/LM**	**Salt: Sand Ratio**
Primary	3.6	3.5	0.5
Rural Commuter	4.3	5.0	0.5
Super Commuter	0.6	11.2	1.0
Secondary	3.6	3.1	0.5
Urban Commuter	3.6	9.0	0.7
ALL	3.5	5.9	0.6

Data based on MNDOT Report PS1A6 – "Sand, Salt, Brine Usage; Coverage Rates by Lane Miles Only" from 10/15/2002 to 4/20/2003

Table 3. TCMA County Road Agency Sand & Salt Application Summary (from: SRF Consulting Group, 1998).

Year	Sand Ap (tons/LM)	Salt Ap (tons/LM)	Sand + Salt Ap (tons/LM) *	% Salt
1994-95	10	5	15	33%
1995-96	15	7	22	32%
1996-97	16	8	24	33%
1997-98	12	7	19	37%
AVG	13.25	6.75	20	33.75%

*Calculated from data in SRF Consulting Group, 1998
Number of counties = 8

As a review of existing literature was undertaken it became obvious that the application rates and mixtures of deicers used are strongly predicated by weather conditions. Initially the concept of wet, dry and average year were proposed as the means of defining the average and extreme conditions. However a further examination of the MnDOT records indicated that the number of "events" per season appeared to be the driving factor in the quantities of material applied (MnDOT, 2003; MnDOT Office of Maintenance. 2003; MnDOT Office of Transportation Data & Analysis, 2002;). There was a limited amount of information as to how these vagarities in weather patterns impacted usage levels by counties and local units of government (SRF Consulting Group, 1998). The MnDOT application guidelines listed below in Table 4 provide some insight into this pattern.

Table 4. MnDOT Sand and Salt Application Guidelines (from: SRF Consulting Group, 1998)

Pavement Temperature	Weather Conditions	Pounds per Two Lane Mile	Operation
30+	Snow	200 - 400	As needed
	Freezing rain	200	Re-apply as necessary
25 - 30	Wet Snow	400 - 500	Re-apply as necessary
	Freezing rain	300	Initial
		200	Re-apply as necessary
20 - 25	Wet snow / sleet	1200 sand/salt	Repeat as necessary
	Freezing rain	1200 sand/salt	Repeat as necessary
15 - 20	Dry snow	1200 sand/salt	Sand hazardous areas 20:1 Sand/salt mixture (stockpile)
	Wet snow / sleet	1200 sand	Repeat as necessary
Below 15	Dry Snow	1200 - 1500	Sand hazardous areas 20:1 Sand/salt mixture (stockpile)

Based upon an assessment of the snow data and usage levels provided by MnDOT for the period of 1971 to 2003 the amount of winter snow was used as a surrogate for the number of events. The high variability in the number of events between regions of the state in any given year, as well the year-to-year variability in the number of events precluded the use of events in this analysis. The winter snow fall amount at MSP Airport was used to define average, dry (low snowfall – 90th percentile) and wet (10th percentile) conditions.

As the concern over and documentation of the environmental impacts of deicing agents has increased, a number of authors and agencies have attempted to document the concentrations of other elements or compounds of concern that are introduced into the environment through road deicing. Some of the earliest studies were in high quality water basins such as Lake Tahoe and the TCMA (Goldman and Hoffman, 1975; Oberts, 1986). Subsequent studies have furthered the analyses and widened the scope of study (Environment Canada and Health Canada, 2001; Fischel, 2001; Lewis, 1999; Public Sector Consultants, 1993; Levelton Engineering, 1998, 1999, and 2000; Tierney and Silver, 2002;). Recent concern over the environmental impacts of chloride has led to searches for alternatives to salt and also widened the concerns for other elements present in these substances. Much of the recent research shows that road salt still is the best alternative for road deicing (Ohrel, 2000). Mangold (2000) references several studies that express concern over the biological oxygen demand exerted on surface waters by the acetate based substitutes and the New York State Attorney

General Office's analysis of the phosphorus content of readily available deicers has heightened concerns for protection of the New York water supply (Tierney and Silver, 2002;). The results from New York and the Levelton Engineering reports (1998, 1999, and 2000) document a wide variety of substances present in deicers and the concern over elevated levels of phosphorus in the deicers derived from agricultural waste products. Table 5 summarizes results from these various analyses and shows the wide variation in phosphorus concentrations among deicers.

Table 5. Phosphorus Concentrations in Deicers

Company or Item	Product or Product Constituent Name	Description	Total Phosphorus (ppm*)
Magnesium Chloride Deicing Products	Sears Ecological Applications Co. $MgCl_2$ (30% solution)**	From Dead Sea	6.2 (1)
	Sears Ecological Applications Co. Magic-O: Laboratory measured value of product consisting of top two components	Ice B' Gone 1 (Spanish Cane) + $MgCl_2$-50:50***	164.8 (1)
	Sears Ecological Applications Co. Magic-O: Estimate calculated from ratio of above two components	Ice B' Gone 1 (Spanish Cane) + MgCl2-50:50	194.2 (1)
	Sears Ecological Applications Co. Magic-O	Ice B' Gone 1 (Venezuelan Cane) + $MgCl_2$-50:50	50.8 (1)
	Sears Ecological Applications Co. Magic-O	Ice B' Gone 1 (Sugar Beet) + $MgCl_2$ 50:50	108.7 (1)
	Sears Ecological Applications Co. Ice B' Gone 2	Synthetic product	0.81 (1)
	Natural Solutions Summit M	Corn Steep residue + $MgCl_2$- 50:50	2281.9 (1); 3692.4(1)#
	Natural Solutions Performance Plus M	Corn Steep residue + $MgCl_2$- 16:84	1556.1 (1); 2062.1(1)#
	Natural Solutions Ultra M	Corn-based product + $MgCl_2$	13.4 (1); 16.7 (1)#
	Natural Solutions $MgCl_2$ (30% solution)**	From Great Salt Lake	13.4 (1); 12.1 (1)#
	SWP Caliber M1000	Manufactured corn product + $MgCl_2$-10:90	109.4 (1)
	SWP Caliber M2000	Manufactured corn product + $MgCl_2$-20:80	249.6 (1)
	SWP $MgCl_2$ w/rust inhibitor		259.5 (1)

	SWP NC-3000	Carbohydrate, potassium carboxylates mix	90.6 (1); 50.5 (1)[##]
	Envirotech FreezGard Zero	$MgCl_2$	42 (5)
	FreezGard Zero (with 4% Ice Ban)	$MgCl_2$	230 (4)
	FreezGard Zero/TEA	MgCl2 + Triethanolamine Inhibitor (5% by weight)	13 (4)
	80% Freezgard + 20% Ice Ban	$MgCl_2$ + Ice Ban	800 (4)
	50% $MgCl_2$ + 50% Ice Ban		2,160 (4)
	Calibre M1000	MgCl2 + 10% Corn-based Inhibitor	76 (4)
Calcium Chloride Deicing Products	Natural Solutions Performance Plus C	Corn Steep residue + $CaCl_2$-50:50	2,133.4 (1)
	Natural Solutions Performance Plus C	Corn Steep residue + $CaCl_2$-16:84	863.2 (1)
	Liquidow $CaCl_2$ (Dow)	$CaCl_2$	30 (4)
	Inhibited $CaCl_2$ (Dow)	CaCl2 with 4% Dow organic inhibitor	53 (4)
	50% $CaCl_2$ + 50% Ice Ban		3,840 (4)
	70% $CaCl_2$ + 30% Ice Ban		2,600 (4)
	80% CaCl2 + 20% Ice Ban		230 (4)
	Calibre C1500	CaCl2 + 15% Corn-based Inhibitor	324 (4)
Other Deicing Products	Sears Ecological Applications Co. Ice B' Gone (concentrate)**	Spanish cane sugar byproduct	323.4 (1)
	Ice Ban	Byproduct from wet milling of corn and alcohol production	10,700 (4)
	Liquid CMA (25%)	Calcium Magnesium Acetate	24 (4)
	Liquid KA (50%)	Potassium Acetate	86 (4)
	Liquid CMAK	50% CMA + 50% KA	120 (4)
Salt	Westchester County salt		4 (1)
	Westchester County salt		1 (1)
	Delaware Co. NYSDOT salt		2 (1)
	Leslie Foods, Newark, California		0.213 (3)

	Utah Salt Co., Salt Lake City, Utah		0.231 (3)
	Southwest Salt Co., Los Angeles, California		25.696 (3)
	Morton Salt Co., Burlingame, California		0.872 (3)
	West Coast Salt & Milling Co., Bakersfield, California		14.312 (3)
	NaCl Brine 23%		<2 (4)
	23% NaCl Brine + 20%Ice Ban		1020 (4)
	NaCl plus 10% Calibre Inhibitor	NaCl + 10% Corn-based Inhibitor	559 (4)
	Minnesota Road Salt		4.6 (2)
	Hennepin County Hwy Dept Salt		1 (6)
Sand	Westchester County sand		53.4 (1)
	Westchester County sand		55 (1)
	Hennepin County Hwy Dept Sand		4.7 (6)
Salt:Sand	Delhi (10:90)		113.5 (1)
	Walton Village (10:90)		55 (1)
	Bloomville salt/sand (10:90)		163.5 (1)
	Colorado Salt/Sand (18:82)		1.91 (5)
	Colorado Salt/Sand (5:95)		3.23 (5)
	Colorado Salt/Sand (5:95)		2.47 (5)

Notes: * ppm = parts per million

** Product constituents = Ice B' Gone 1 concentrate and MgCl2 or magnesium chloride salt (30% solution)

*** 50:50 = A ratio consisting of 50% Ice B'Gone 1 and 50% MgCl2.

Sample re-analyzed

Product was analyzed twice with a duplicate analysis each time. Agreement between duplicates was poor and outside quality control limits. Results of the four analyses ranged from 14.9 to 112.8 ppm. Lab concluded that there was interference with this sample and the method.

Source: (1) Office of NY Sate Attorney General, 2002. Scientific Guidance on Lower-Phosphorus Roadway De-icers http://www.oag.state.ny.us/environment/deicer.html

(2) Biesboer and Jacobson, 1993.

(3) Goldman and Hoffman, 1975.

(4) Levelton Engineering Ltd. 1998.

(5) Lewis, 1999.

(6) Oberts, 1986.

Phosphorus Concentrations in Deicing Agents

Unfortunately much of the analysis done for phosphorus content have not been conducted under any type of standard testing protocol; as such much of the available data had to be converted to a standard measure of phosphorus concentration. For purposes of this analysis, all of the data was converted to concentration in parts per million (mg P/L or mg P/kg). The statistical summary data presented in Table 5 for salt, sand and salt/sand mixtures were the used for the phosphorus load calculations completed for the deicing agents for each of the basins.

Table 5a. Summary statistics for salt, sand and salt/sand mixtures; all values in ppm – phosphorus.

	Salt (NaCl)	Sand	Sand salt mixes
Mean	4.99	37.70	33.93
Std. Dev.	7.97	28.59	55.05
Number	11	3	13

Watershed Basin Characteristics

The literature review made it obvious that the application rates and mixtures of deicers used are strongly predicated by weather conditions that are not always closely related to total annual precipitation levels. An assessment was completed for the snow and deicer usage levels provided by MnDOT for the period of 1971 to 2003. The lack of long term data on number of events, coupled with the high variability in the number of events between regions of the state in any given year and the year-to-year variability in the number of events precluded the use of events in this analysis. Based upon this data the amount of winter snow was used as a surrogate for the number of events, as the number of events is the main determinant for the amount of sand used in a winter season. Based upon this data the winter snow fall amount at MSP Airport was used to define average, dry (low snowfall – 90th percentile) and wet (10th percentile) conditions. The amount of deicer usage (sand and salt) varied between road class service levels, as did the ratio of sand and salt. The variation in weather patterns that determine the deicer usage appear to be too complex to define accurately across all of the basins on a year-to-year basis, so weather variability based upon annual snow fall and ratios established between the districts was based upon the best data years (1994-98 and 2002-03). Table 8 provides a tabular summary of the weather pattern, usage variability and the conditions selected for average, wet and dry years.

The initial attempt to estimate salt usage for the three scenarios was based upon these same conditions and assumptions. A subsequent assessment of those results and the actual MnDOT usage levels proved those assumptions to be invalid. Conversations with MnDOT staff strongly suggested that another estimation alternative would be needed to accurately predict the salt usage over the different weather conditions. The total season usage levels of salt are more strongly influenced by the number of events than the amount of snow, so the assumptions for sand and snowfall do not apply to salt. Also, since the implementation of the Salt Solutions study, the use of sand has been reduced and the amount of salt used has become more stable from year-to-year (Vasek, 2003). The salt usage rates that were used in the overall basin loading estimates are constant from year-to-year, but are variable with regard to road type. These results were compared for accuracy and uncertainty to salt use data for the last sevens years – the time period that coincides with implementation of the Salt Solutions study.

MnDOT deicer usage data for the winters of 1994 – 1998 and the winter of 2002 – 2003 were also analyzed to determine the differences in application rates for the various portions of the state based upon the MnDOT Maintenance Districts and sub-district boundaries (SRF Consulting Group, 1998; MnDOT, 2003). This data shows that the Metro, Northeast and Southeast maintenance districts have the highest application rates for deicers (see Table 6). An analysis was completed for the state highway application rates for the Metro District and these were then adjusted based upon the variation for application rates with the individual districts to estimate lane miles applications rates for the three scenarios.

MnDOT databases and GIS were used to develop road miles for each county in the state and then the road miles were distributed by basin based upon area-weighting within county boundaries. Roads were categorized based upon the road type and lane miles as per Table 7.

Table 6. MnDOT Maintenance District Deicer Usage Rates Data – Comparison of Usage Rates for the Winter of 2002 – 2003

"Dry year" (Winter of 2002 – 2003) District	Service Level	Average Sand (Tons)/LM	Average Salt (Tons)/LM	Average Brine (Gals)/LM	Salt + Sand (Tons)/LM	Percent Salt+Sand Use – higher/lower than Metro	Total Miles Serviced
1	ALL	7.83	6.93	70.9	14.76	25%	3784
1A	ALL	6.6	7.01	48.15	13.61	15%	2010
1B	ALL	9.41	6.93	99.06	16.34	38%	1728
2	ALL	3.5	2.5	9.62	6	-49%	3904
3	ALL	3.52	5.75	62.12	9.27	-22%	3987
3A	ALL	5.1	5.46	40.3	10.56	-11%	1921
3B	ALL	1.96	5.77	80.75	7.73	-35%	2066
4	ALL	3.41	3.46	40.81	6.87	-42%	3588
METRO	ALL	0.4	11.43	8.63	11.83	0%	5333
6	ALL	4.52	7.95	62.42	12.47	5%	3691
6A	ALL	7.51	7.44	75.36	14.95	26%	1917
6B	ALL	1.28	8.5	48.44	9.78	-17%	1774
7	ALL	2.24	3.25	36.31	5.49	-54%	3217
7E	ALL	1.27	3.62	44.52	4.89	-59%	1631
7W	ALL	3.13	2.78	26.95	5.91	-50%	1639
8	ALL	3.62	2.61	42.57	6.23	-47%	2928
STATEWIDE	ALL	3.49	5.91	40.08	9.4	-21%	30386

Table 7. Total road lane miles by basin.

Road Type	Upper Mississippi River (Lane Miles)	St. Croix River (Lane Miles)	Red River of the North (Lane Miles)	Rainy River (Lane Miles)	Missouri River (Lane Miles)	Minnesota River (Lane Miles)	Lower Mississippi (Lane Miles)	Lake Superior (Lane Miles)	Des Moines River (Lane Miles)	Cedar River (Lane Miles)
Interstate Trunk Highway	2,558	890	497	0	497	1,175	1,224	290	191	550
U. S. Trunk Highway	3,718	71	2,237	368	134	2,143	1,852	726	155	159
Minnesota Trunk Highway	5,470	890	2,654	1,256	319	4,211	1,695	880	336	187
County State-aid Highway	16,640	2,705	11,779	2,456	1,761	14,768	6,652	2,871	1,538	1,207
Municipal State-aid Street	3,799	202	254	18	10	1,271	660	515	13	130
County Road	7,980	1,510	6,113	2,136	839	6,273	1,909	2,556	382	354
Township Road	26,665	4,185	27,859	1,210	3,713	28,613	11,425	1,801	3,285	2,035
Unorganized Township Road	554	68	578	1,686	0	0	0	379	0	0
Municipal Street	16,886	1,696	1,821	269	305	6,235	3,649	1,713	368	497
National Forest Development Road	831	0	0	816	0	0	0	1,000	0	0
Indian Reservation Road	83	0	633	94	0	0	0	0	0	0
State Forest Road	667	159	579	1,011	0	0	116	270	0	0
State Park Road	29	58	27	16	2	17	16	6	1	1
National Wildlife Refuge Road	0	0	0	0	0	10	0	0	0	0
Frontage Road	0	0	0	0	0	0	0	2	0	0
Ramp	331	31	30	2	11	155	72	26	4	27
Private Jurisdiction Road	17	3	0	0	0	35	0	0	0	0
Other	15	2	5	61	1	14	2	3	1	0
Total	86,240	12,469	55,066	11,399	7,592	64,919	29,271	13,038	6,275	5,147

Table 8. Summary statisatics for MnDOT deicing applications for winters 1971 - 2003 and 1996 - 2003.

1971 - 2003	Snowfall (inches)	Sand (Tons)	Sand Applied (Tons/LM)	Chemical Applied (Salt Tons)	Salt Applied (Tons/LM)	Sand+Salt Applied (Tons)	Sand+Salt Applied (Tons/LM)	Percent salt (tons/LM)
MAX =	99	397,798	13	251,159	8	620,448	20	75%
MIN =	17	106,478	4	56,295	2	224,634	7	34%
AVG =	58	279,765	9	154,956	5	434,721	14	64%
90th %ile	36	284,157	6	150,031	3	431,827	11	52%
Median	57	367,906	9	229,040	5	558,405	14	68%
10th %ile	76	174,393	12	95,325	8	326,804	18	72%
>90th %ile mean	24	177,818	6	117,483	4	295,301	10	60%
Mean	58	279,765	9	154,956	5	434,721	14	64%
<10th %ile mean	92	311,035	10	142,937	5	453,971	15	69%
1996 - 2003								
MAX =	76	369,289	12	251,159	8	620,448	20	59.5%
MIN =	35	106,478	4	171,087	6	287,039	9	33.6%
AVG =	55	220,529	7	215,445	7	435,974	14	48.6%
Median	57	229,263	8	222,894	7	441,526	15	51.9%
Median	57	229,263	8	222,894	7	441,526	15	51.9%

* Assumes 30,386 Total Miles Serviced Statewide (2002-03 MNDOT data) for 1971 - 2003 time period

** Within percentile values used for analysis based upon >10th %tile and <90 %tile, respectively for 1971 - 2003 only

Approach and Methodology for Phosphorus Loading Computations

Phosphorus loading computations were primarily based upon the MnDOT data sources as this was the most detailed data set and extended over the longest time period. Loading calculations for TCMA counties were from SRF Consulting Group (1998) and other road types were extrapolated using the MnDOT data trends, applications rates and deicing mixtures. The following discussion of loading rate calculations is organized around the application of deicing agents to the road classification based upon level of government maintaining the particular road type.

MnDOT Maintained Roads:

As has been previously mentioned, the MnDOT database was the most comprehensive and most useful in determining application rates across the range of conditions for wet, dry and average years. Table 8 presented the summary of weather patterns and application rates for the 1971 – 2003 time period. This data assessment shows that dry years result in decreased usage and wet years increase usage rates. The period of record used in this analysis was not used any further for the loading calculations as much of the data is from winters prior to the Salt Solutions Report (SRF Consulting Group, 1998) and thus may not be indicative of current winter road maintenance practices. It does however provide strong support for the adjustment of application rates due to weather variability from year-to-year based upon snowfall amounts.

The applications rates for each MnDOT District, and thus for each basin, is based upon the use of statewide averages based upon their relationship to snowfall amounts over a winter. Application rates for salt and sand were then adjusted to account for the wet, dry and average conditions based upon the ratios derived from the 1971 – 2003 time period and the relationship between the years of detailed information provided in the Salt Solutions Report and MnDOT's Work Management System Reports (SRF Consulting Group, 1998; MnDOT, 2003;). See Tables 9 – 11 for the results of these calculations for salt, sand and brine use for each scenario for the state highway types.

The use of brine for deicing has increased in recent years, but the period of record for its application is limited and thus 2002 rates were used in the calculations as insufficient data was available to attempt to adjust for year-to-year variability in its application rate. The NaCl brine solution used by MnDOT is a 26% solution having a delivered concentration of phosphorus of 0.49 ppm per gallon. MnDOT has also recently started use of $MgCl_2$, with 78,199 gallons applied in 2002 – 03 in Districts 1, 2 and 3 combined. MnDOT uses a number of different $MgCl_2$-based deicing agents in various quantities; Calibre M1000, Calibre M2000, 30% $MgCl_2$, and Freezgard Zero. The current data does not provide a breakdown of the amounts of each deicer, but if for discussion purposes the total volume applied was for each of the alternative compounds then the quantity of phosphorus would be as follows:

Deicing Compound	Phosphorus concentration	Kg of P for 78,199 gallons per year
Calibre M1000	76 ppm P	1.6 kg P
Calibre M2000	249 ppm P	5.1 kg P
30% $MgCl_2$	6.2 ppm P	0.13 kg P
Freezgard Zero	42 ppm P	0.87 kg P

The limited quantity of phosphorus involved in this current use (less than 0.001% of annual deicer load), the short-term experience for use of these compounds, and limited records of use did not warrant its inclusion in this analysis.

Table 9. MnDOT Dry Year Deicer Usage Rate Calculations Based Upon 2002 - 2003 (Dry Year) Recorded Usage

"Dry year"	Average Sand (Tons)/LM	Average Salt (Tons)/LM	Average Sand (Tons)/LM	Average Salt (Tons)/LM	Average Sand (Tons)/LM	Average Salt (Tons)/LM	Average Brine (Gals)/LM
District	Interstate Trunk Highways		US Trunk Highways		Minnesota Trunk Highways		All State Roads
1	0	14.76	4.43	10.33	7.38	7.38	70.9
1A	0	13.61	4.08	9.53	6.81	6.81	48.15
1B	0	16.34	4.90	11.44	8.17	8.17	99.06
2	0	6.00	1.80	4.20	3.00	3.00	9.62
3	0	9.27	2.78	6.49	4.64	4.64	62.12
3A	0	10.56	3.17	7.39	5.28	5.28	40.3
3B	0	7.73	2.32	5.41	3.87	3.87	80.75
4	0	6.87	2.06	4.81	3.44	3.44	40.81
METRO	0	11.83	3.55	8.28	5.92	5.92	8.63
6	0	12.47	3.74	8.73	6.24	6.24	62.42
6A	0	14.95	4.49	10.47	7.48	7.48	75.36
6B	0	9.78	2.93	6.85	4.89	4.89	48.44
7	0	5.49	1.65	3.84	2.75	2.75	36.31
7E	0	4.89	1.47	3.42	2.45	2.45	44.52
7W	0	5.91	1.77	4.14	2.96	2.96	26.95
8	0	6.23	1.87	4.36	3.12	3.12	42.57

Table 10. MnDOT Average Year Deicer Usage Rate Calculations Based Upon 2002 - 2003 (Dry Year) Recorded Usage

"Average year"	Average Sand (Tons)/LM	Average Salt (Tons)/LM	Average Sand (Tons)/LM	Average Salt (Tons)/LM	Average Sand (Tons)/LM	Average Salt (Tons)/LM	Average Brine (Gals)/LM
District	Interstate Trunk Highways		US Trunk Highways		Minnesota Trunk Highways		All State Roads
1	0	14.76	9.32	10.33	15.53	7.38	70.9
1A	0	13.61	11.18	9.53	18.63	6.81	48.15
1B	0	16.34	4.13	11.44	6.89	8.17	99.06
2	0	6.00	6.32	4.20	10.53	3.00	9.62
3	0	9.27	7.21	6.49	12.02	4.64	62.12
3A	0	10.56	5.27	7.39	8.78	5.28	40.3
3B	0	7.73	4.70	5.41	7.83	3.87	80.75
4	0	6.87	8.10	4.81	13.50	3.44	40.81
METRO	0	11.83	8.51	8.28	14.18	5.92	8.63
6	0	12.47	10.21	8.73	17.01	6.24	62.42
6A	0	14.95	6.72	10.47	11.21	7.48	75.36
6B	0	9.78	3.73	6.85	6.21	4.89	48.44
7	0	5.49	3.32	3.84	5.54	2.75	36.31
7E	0	4.89	4.05	3.42	6.75	2.45	44.52
7W	0	5.91	4.29	4.14	7.16	2.96	26.95
8	0	6.23	0.00	4.36	0.00	3.12	42.57

Table 11. MnDOT Wet Year Deicer Usage Rate Calculations Based Upon 2002 - 2003 (Dry Year) Recorded Usage

"Wet year"	Average Sand (Tons)/LM	Average Salt (Tons)/LM	Average Sand (Tons)/LM	Average Salt (Tons)/LM	Average Sand (Tons)/LM	Average Salt (Tons)/LM	Average Brine (Gals)/LM
District	Interstate Trunk Highways		US Trunk Highways		Minnesota Trunk Highways		All State Roads
1	0	14.76	16.88	10.33	28.13	7.38	70.9
1A	0	13.61	15.53	9.53	25.88	6.81	48.15
1B	0	16.34	18.63	11.44	31.05	8.17	99.06
2	0	6.00	6.89	4.20	11.48	3.00	9.62
3	0	9.27	10.53	6.49	17.55	4.64	62.12
3A	0	10.56	12.02	7.39	20.03	5.28	40.3
3B	0	7.73	8.78	5.41	14.63	3.87	80.75
4	0	6.87	7.83	4.81	13.05	3.44	40.81
METRO	0	11.83	13.50	8.28	22.50	5.92	8.63
6	0	12.47	14.18	8.73	23.63	6.24	62.42
6A	0	14.95	17.01	10.47	28.35	7.48	75.36
6B	0	9.78	11.21	6.85	18.68	4.89	48.44
7	0	5.49	6.21	3.84	10.35	2.75	36.31
7E	0	4.89	5.54	3.42	9.23	2.45	44.52
7W	0	5.91	6.75	4.14	11.25	2.96	26.95
8	0	6.23	7.16	4.36	11.93	3.12	42.57

Application rates for state highways for all Districts used for the “dry” year scenario used application rates based upon the recorded uses for the winter of 2002 – 03. The level of detail in Work Management System Reports allowed for the development of usage rates for each of the districts and some of the sub-districts. Salt usage rates remained constant at the 2002 – 2003 rates throughout the three loading scenarios and varied based upon the sand/salt ratios described for each service level below.

“Wet” year conditions were calculated using the Metro District data for the winters of 1995 – 97 and then adjusting for the other district usage rates based upon percentage differences using the 2002 – 03 data. While the years of 1995 – 97 were not within the 10^{th} percentile of the years from 1971 – 2003 dataset, they were the wettest years for the time period since the implementation of the Salt Solutions Report recommendations and are the usage estimates that provided the closest agreement with actual use rates for sand (SRF Consulting Group, 1998).

“Average” year conditions and sand usage rates were calculated in a similar fashion using the winter of 1994 – 95 data and extrapolating to the other districts. Development of usage rates to the sub-district level allowed for a finer scale of estimation as to state highway loadings across the basins. See Figure 1 for MnDOT District, sub-district and watershed basin boundaries.

MnDOT’s road classes (service levels) were used to further define the application assumptions for the mix ratios of deicers used on the three road types maintained by MnDOT. Based upon and examination of the 2003 – 02 deicer usage report the total salt plus sand application, in tons per lane mile, was modified for the three types of roads maintained by MnDOT (MnDOT, 2003a).

- 01 - Interstate Trunk Highway – uses a 100% salt assumption (assuming "super commuter" service level)
- 02 - U.S. Trunk Highway – uses a 70% salt assumption (assuming "urban commuter" service level)
- 03 - Minnesota Trunk Highway – uses a 50% salt assumption (assuming "rural commuter" service level)

County and Local Government Maintained Roads:

County and local road agency specific data was less readily available for use in this analysis, except for the TCMA counties (SRF Consulting Group, 1998). An analysis was undertaken using the 1994 – 1997 data available for the TCMA to develop usage rates for the County State Aid Highway (CSAH) system. The TCMA deicer usage rates were summarized based upon average conditions (1994 – 95) for both salt and sand usage on a lane mile basis. The 1995 – 1997 period was used for calculation of the wet year conditions. The dry year conditions were used based upon the 90^{th} percentile summary statistics presented in Table 8. These usage numbers were applied to all CSAH miles across the state as they were viewed as the more heavily traveled and thus more highly maintained roads in both the TCMA and out-state areas. These usage numbers are conservatively high based upon the sand to salt ratios reported in the Minnesota Legislative Auditor (1995) report, with a salt percentage of 33%. The sand and salt application rates used for this analysis are shown in Table 12.

Table 12. Sand and Salt Application Rates for County State Aid Highways for Loading Calculations.

Year	Sand (tons/LM)	Salt (tons/LM)
Dry	7.1	3.2
Average	10.0	5.0
Wet	15.5	7.5

Deicer usage rates for other county highways and local roads were developed based upon an even smaller database of actual usage rates. As such, the usage rates for the “rural” counties in the TCMA – Scott, Carver and Chisago counties – were used to develop usage rates for other roads included in this analysis. An analysis was undertaken using the 1994 – 1997 data available for these TCMA in manner consistent with the CSAH analysis described above. Again this estimate is conservatively high due to a lack of actual applications rate up0n which to further refine the estimates. Those rates are presented in Table 13.

Table 13. Sand and Salt Application Rates for County and Local Roads for Loading Calculations.

Year	Sand (tons/LM)	Salt (tons/LM)
Dry	3.8	1.4
Average	6.0	2.0
Wet	7.5	2.5

Results of Phosphorus Loading Computations and Assessments

The basin loading calculations were computed using the application rates and concentrations defined in the Approach and Methodology section for the lane miles in each basin. Each basin calculation was completed using the application rates for the respective MnDOT Districts that encompass the basin; whenever the basin includes TCMA counties, those state highway lane miles were calculated using the higher Metro District rates for each county. Table 14 provides a summary of the district and Metro counties included in each basin calculation.

Table 14. Summary of the district and Metro counties included in each basin calculation.

Basin	MnDOT District (state roads)	Metro District (Metro counties)
St. Croix River	1A	Chisago, Ramsey, Washington
Upper Mississippi River	3	Anoka, Carver, Dakota, Hennepin, Ramsey, Washington
Lower Mississippi River	6	Dakota, Scott
Red River	2 & 4 avg	
Rainy River	1B	
Lake Superior	1A	
Missouri River	7W	
Minnesota River	7 & 8 avg	Carver, Dakota, Hennepin, Scott
Cedar River	6B	
Des Moines River	7W	

Table 15 presents the phosphorus loading results for each of the basins under the three loading scenarios and a summary for the state-wide total phosphorus load from deicing agents under the same three scenarios.

Table 15. Phosphorus loading results for Minnesota basins and state-wide totals for three snowfall scenarios.

Basin	Snowfall Scenario	Tons of Salt	Tons of Sand	Gallons of Brine	Kg P from Salt	Kg P from Sand	Kg P from Brine	Total Kg P
St. Croix River	Dry Year	37,525	55,343	59,431	170	1893	0.03	2,063
	Avg Year	47,143	88,364	59,431	213	3022	0.03	3,236
	Wet Year	57,862	124,331	59,431	262	4252	0.03	4,514
Upper Mississippi River	Dry Year	214,976	376,477	521,969	973	12876	0.26	13,849
	Avg Year	279,640	600,253	521,969	1266	20529	0.26	21,795
	Wet Year	350,167	835,955	521,969	1585	28590	0.26	30,176
Lower Mississippi River	Dry Year	88,034	132,454	268,117	399	4530	0.13	4,929
	Avg Year	110,716	213,189	268,117	501	7291	0.13	7,793
	Wet Year	136,270	302,924	268,117	617	10360	0.13	10,977
Red River	Dry Year	112,554	240,506	135,874	510	8226	0.07	8,735
	Avg Year	156,495	374,579	135,874	708	12811	0.07	13,519
	Wet Year	204,893	546,846	135,874	928	18703	0.07	19,630
Rainy River	Dry Year	32,576	57,318	160,864	147	1960	0.08	2,108
	Avg Year	41,389	95,993	160,864	187	3283	0.08	3,470
	Wet Year	51,190	138,824	160,864	232	4748	0.08	4,980
Lake Superior	Dry Year	37,625	60,767	91,289	170	2078	0.04	2,249
	Avg Year	47,755	98,765	91,289	216	3378	0.04	3,594
	Wet Year	59,068	140,577	91,289	267	4808	0.04	5,075
Missouri River	Dry Year	16,903	32,231	25,586	77	1102	0.01	1,179
	Avg Year	23,002	49,589	25,586	104	1696	0.01	1,800
	Wet Year	29,845	68,392	25,586	135	2339	0.01	2,474
Minnesota River	Dry Year	141,111	285,517	251,770	639	9765	0.12	10,404
	Avg Year	193,267	446,062	251,770	875	15256	0.12	16,131
	Wet Year	251,497	589,445	251,770	1138	20160	0.12	21,298
Cedar River	Dry Year	15,504	21,514	43,379	70	736	0.02	806
	Avg Year	19,503	33,493	43,379	88	1145	0.02	1,234
	Wet Year	24,042	46,803	43,379	109	1601	0.02	1,710
Des Moines River	Dry Year	13,370	27,606	18,403	61	944	0.01	1,005
	Avg Year	18,573	42,620	18,403	84	1458	0.01	1,542
	Wet Year	24,447	59,097	18,403	111	2021	0.01	2,132

		Tons of Salt	Tons of Sand	Gallons of Brine	Kg P from Salt	Kg P from Sand	Kg P from Brine	Total Kg P
Statewide Totals	Dry Year	710,178	1,289,734	1,576,683	3,215	44,110	0.77	47,326
	Avg Year	937,483	2,042,906	1,576,683	4,244	69,869	0.77	74,114
	Wet Year	1,189,280	2,853,194	1,576,683	5,384	97,582	0.77	102,966

Phosphorus Loading Variability and Uncertainty

All of the loading estimates prepared for phosphorus from deicing agents were based upon information reported by road maintenance agencies whenever possible. MnDOT and other agencies readily acknowledge that better record keeping is needed and better measurements are needed to document the actual usage numbers (SRF Consulting Group, 1998; Weber, 2003;). While MnDOT data is of relatively high quality, the near absence of local road agency data for use in this analysis creates concern for the accuracy of the final numbers beyond those for state maintained roads, given the amount of variability that currently exists due to year-to-year weather patterns and the resulting deicer usage patterns. For this uncertainty analysis we have confined the actual MnDOT usage data to the 1996 – 2003 time period. This period is the period of time that includes MnDOT operations since the start of implementation for the Salt Solutions study recommendations and most accurately represents current deicer use trends for the state highway system (Vasek, 2003).

Based upon a state-wide sum of salt and sand usage for MnDOT maintained roads and the reported state-wide deicer use data from MnDOT has allowed for an analysis of the loading estimate uncertainty against actual application information. The estimation methods were assessed against actual MnDOT usage levels and those results are summarized in Table 16, for the wet, average and dry years based upon a comparison to actual application quantities for similar years. The usage estimation for sand and salt usage, and thus the phosphorus load estimates from MnDOT uses for the three scenarios are reasonable given the limitations of the data (+/- 22%). The MnDOT salt usage estimate for the “average” year, i.e., for those years of data upon which the other scenario estimates were constructed has a smaller error than for the sand and brine. The error for Brine is about 30% , but the phosphorus loading due to brine is less than 0.001% of the total phosphorus load and thus is insignificant. Without further data for other road agencies the accuracy of the other estimates can only be assumed to be similar. Table 17 presents a breakout for the estimated MnDOT deicer usage by scenario for each basin.

Much of the phosphorus content analysis for these deicing agents has been collected from widespread sources having differing and sometime poorly documented analysis methods. The limited number of studies and the ongoing citation of a few early studies by current investigators suggest that more analytical studies on deicing agents and phosphorus should be completed. The summary statistics for the data on salt and sand gleaned from the literature presented in Table 5, highlight the relative lack of data on the subject and the variability of concentrations. Many of these analyses results are from across the U.S.; a data set that is confined to deicing agents used in Minnesota would provide a more accurate estimate of the loads.

Table 16. Comparison of calculated and actual statewide deicer usage on Minnesota state

Snowfall Scenario Database Year(s)	Calculated Tons sand	Actual Tons sand	% Difference (calc/actual)
Calculated dry year 2002 - 03	118,358	106,478	111.16%
Calculated average year Mean 1996 - 2003	268,874	220,529	121.92%
Calculated wet year 1996 - 1997	448,522	369,289	121.46%
	Calculated Tons salt	Actual Tons salt	Difference %
Calculated Median 1996 - 2003	242,177	222,894	108.65%
	Calculated Gallons Brine	Actual Gallons Brine	Difference %
Calculated average year 2002 -2003	1,576,683	1,215,915	129.67%

Table 17. Estimated deicer usage totals by basin for Interstate, US Trunk and Minnesota Trunk highways.

Basin	Low Year Salt (tons)	Low Year Sand (tons)	Avg Year Salt (tons)	Avg Year Sand (tons)	High Year Salt (tons)	High Year Sand (tons)	Brine (gallons)
Upper Mississippi River	80,732	38,486	80,732	86,725	80,732	144,126	521,969
St. Croix River	17,789	6,065	17,789	13,830	17,789	23,048	59,431
Red River	21,801	12,857	21,801	29,393	21,801	80,026	135,874
Rainy River	14,469	12,066	14,469	27,515	14,469	45,858	160,864
Missouri River	4,434	1,180	4,434	2,692	4,434	4,487	25,586
Minnesota River	34,183	18,699	34,183	42,648	34,183	40,875	251,770
Lower Mississippi River	41,761	17,404	41,761	39,583	41,761	65,961	268,117
Lake Superior	16,858	8,954	16,858	20,431	16,858	34,046	91,289
Cedar River	7,381	1,378	7,381	3,159	7,381	5,265	43,379
Des Moines River	2,769	1,270	2,769	2,899	2,769	4,831	18,403
Estimated MnDOT Deicer Use	242,177	118,358	242,177	268,874	242,177	448,522	1,576,683
Estimated Total Deicer Use	710,178	1,289,734	1,246,445	2,042,906	1,868,976	2,853,194	1,576,683
MnDOT Percentage	34.1%	9.2%	19.4%	13.2%	13.0%	15.7%	100.0%

Recommendations for Future Refinements

See previous section for relevant discussion.

Recommendations for Lowering Phosphorus Export

Efforts currently underway as part of MnDOT's road weather information system (RWIS) use timely and accurate weather and road data in deicing application decisions; these efforts have optimized the use of deicing materials. The Minnesota Legislative Auditor (1995) reported that "(M)ost counties (93 percent), cities providing their own service (91 percent), and townships providing their own service (59 percent) rely on television or radio weather reports, including the National Weather Service reports via telephone, for weather information." More accurate weather information could lead to reduced usage of deicing agents. The use of brines can also improve the effectiveness of deicing agents and in all cases where the quantities of deicers are reduce there as cost savings to the road agency and safety benefits to the public.

The high phosphorus content of many of the agriculturally derived alternatives to road salt is noteworthy. In most cases the high phosphorus content for the alternatives is due to the corrosion inhibitor portion of the mixtures. As concerns for the environmental impacts has chlorides increased, additional emphasis may be placed on the use of these alternatives. While this analysis does not make any attempt to quantify what those impacts would be, a cursory evaluation of the concentrations shows that many of these products have phosphorus concentrations 100 to 10,000 times greater than road salt or sand.

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